

< ABSTRACT >

The Efficiency of Capturing True Reaction Times in Tissue

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Background and Objectives: The skin comprises the epidermis and the dermis and often contains unwanted items such as hair and vascular lesions.

Targeting those items is a function of:

1. The wavelength to determine depth and nature of the target.
2. The power and spot size to generate a specific amount of heat to alter the target.
3. The time period in which the energy is delivered.

Most unwanted hair and vascular targets have very similar size and shape (60-100 micron cylinders) and therefore have very similar ideal pulse times.

Pigmented lesions are not as thick as the diameter of the unwanted hair or vessel but exist in a sheet, which has about twice the thermal relaxation time (TRT) resulting in the need for a similar 3-5 millisecond pulse time.

Conclusions: It is generally agreed by practitioners, when the choice of pulse times between 3 and 5 milliseconds exists, it is better to select 5 milliseconds for the sake of patient safety and reduced discomfort. Longer pulse times (10 milliseconds or beyond) do not have the same ability to match the natural physical responses of these targets and therefore much more energy is required of those devices using longer pulse times and with a higher risk of complications.

INTRODUCTION

The first law of photochemistry (Grotthus-Draper Law, 1818) dictates that there is no reaction without absorption of energy. This precept applies as one observes and controls light on skin. Both lasers and intense pulsed light sources transmit energy to skin in order to alter specific components in tissue through absorption and resultant heat. *Examples of these processes include:*

1. Removal of unwanted hair
2. Reduction of vascular lesions
3. Reduction of pigmentation spots

The control of the heating process determines the target, its location, and the temperature of the target for a controlled period of time. It is accepted that the changes sought in tissue, i.e. the resolution of both haemoglobin and melanin based lesions, come through heating the unwanted lesion to a specific temperature. (*See Table 1 – p. 2*)

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° C		w/cm ²
450	Ablation	15,000
100	Boiling	1,200
90	Dessication	500
75	Denaturization and Necrosis	400
65	Protein Destruction	300
60	Coagulation	5
37	Normal Temp	

Table 1: Comparison of power density and temperature effects on body components.

The temperatures needed for a specific change are predictable and controllable. A specific amount of light delivered in a specific physical spot size or footprint (power density or watts/cm²) will result in a determined thermal heating and resultant change. However, the precepts of Selective Photothermolysis indicate that the change is a result of both a specific thermal heating and, logically, a specified period of time (wavelength, power, spot size, and time period).

This may be illustrated as follows:

1. A pan of water placed on top of a heated stove will not spontaneously boil.
2. There is a calculable period of time for the pan of water to boil based on the heat available, the target temperature selected.
3. The volume (target) to be heated.

Once heated, and in fact during the entire heating process, the volume of water is acting to expend the heat introduced. As targets are heated they are acting to cool themselves by dissipation of the heat introduced.

Two different sized pans of water subjected to the same rate of heating will reach the selected temperature in different periods of time. A smaller volume will reach the selected temperature in a shorter period of time than the larger. In addition, when the heating ceases, the smaller volume will return to ambient temperature faster than the larger volume.

There are two physical properties involved in these rates, the volume and surface area of the target.

The volume controls the ability to collect and retain heat. Surface area and target shape dictate the rate of heat release through conduction into surrounding environs. As a target increases in size, the volume ($\frac{4}{3} \pi r^3$), grows at a faster rate than does the surface area ($4 \pi r^2$). Larger targets therefore require longer (larger) heating and cooling times. (See Figure 1 - p. 3)

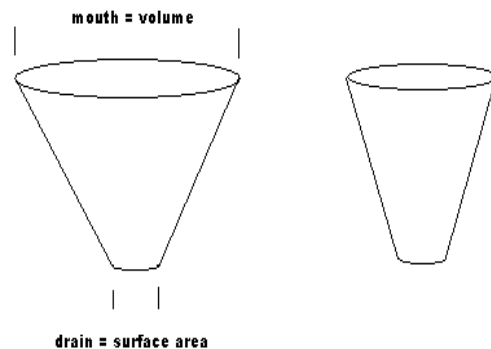


Figure 1:
Demonstration that volume
grows at a greater rate than
surface area.

IMPLICATIONS IN CLINICAL PRACTICE

When targeting an unwanted lesion in clinical practice, the goal is the selected and controlled thermal change (destruction or modification) within the target without thermally affecting surrounding tissue components (hence the term Selective Photothermolysis).

The heating of surrounding components often results in unwanted injury or complication. The time period of the heating and the resultant reaction are critical for predictable success without complications, such as burning, and the type and physical shape of each target tissue determines those ideal numbers. If the response time is ignored, it will still allow heating of the target in a significantly less controlled manner, hence increasing the risk of concurrent injury and complication.

Selective Photothermolysis was first applied to the elimination of small vessels, 20–100 microns in diameter, found in port wine stains. The formula for selecting the ideal heating time for a target is based primarily on the ideal cooling time of the target. The cooling, or dissipation time, is referred to as Thermal Relaxation Time. Simply stated, it is the time for a target to return to ambient temperature.

As an analogy, consider all skin targets as funnels of differing mouth and drain sizes determined by the size of the target. Targets have mouths (like volume) and drain sizes (like surface area) determined by their physical size and shape. Larger targets have mouths proportionally larger than the drains since volume increases at a greater rate than surface area (see Figure 1). Hence, larger targets have a greater ability to backfill (i.e. they can be filled at a slower rate than a smaller target with the same result).

A thermometer indicates a higher temperature as retained heat increases resulting in a 'higher' reading on its scale based on the internal volume measured. In heating tissue targets, the goal is not just to apply heat, but to apply heat at a rate enabling an increase in the retained volume of the target. For example, if the funnel analogy is considered again, the goal is not to transfer heat (fluid) through the funnel but rather to backfill so that it will retain a higher volume of fluid within the funnel (target) by introducing heat at a rate faster than it can be dissipated. Holding a 1 litre funnel one can pour 5 litres (4 or 5 times the volume) at a very slow rate and never achieve any backfill but the 5 litres of water (heat) has spilled into the surrounding area.

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However, if the 1 litre funnel is filled at a faster rate one can use even less than 1 litre of water if the goal is to backfill the funnel to a 75% point (equated to a goal temperature of 65-75⁰ C for change). Filling stops the instant the 75% level is reached and the retained volume (less than one-fourth litre) will then drain into the surrounding area (symbolizing heat retained) with faster rates. Each target in tissue has an ideal rate of energy delivery to quickly and efficiently heat it to the point of change. The ideal fill time is agreed to be about one-half the drain time, that is the Thermal Relaxation Time (TRT). This ideal time can be referred to as Thermal Containment Time (TCT). If the TRT of a 60-100 micron vessel is 5-10 milliseconds then the average ideal pulse time would be one-half that or 3-5 milliseconds. The average hair shaft diameter of unwanted hair is about 60 -100 microns and the average unwanted facial vessel in telangiectasia, rosacea, or a port wine stain is approximately 60-100 microns in diameter. Therefore, the average pulse time for both would be about 3-5 milliseconds.

Newton taught that white light was actually an amalgam of all visible colors. As one looks across the visible spectrum, there is a transition from the Ultraviolet to the Infrared. Infrared energy has a much greater depth of penetration in skin than does Ultraviolet light. In this manner, yellow light cannot penetrate as deeply as red light, which tends to dwell in the epidermis and the upper dermis, the zone of smaller vascular lesions. Red light will pass through tissue's upper structures without absorption seeking the deeper pigmented target like hair follicles. Unfiltered intense pulsed light (with the blue and green components present) tends to be very superficial and deposits most of its energy in superficial targets like pigmented lesions.

Pigmented lesions may seem at first sight to be much thinner in physical dimension than vascular or hair targets and that perception is true. It would therefore seem true, that a shorter pulse time would be ideal. A shorter pulse would focus more of the energy in the epidermis but the risk of complication (blistering, hyperpigmentation, hypopigmentation, and scarring) escalates. Pigment in a cell is a hood or blanket that does not penetrate the depth of the cell but only covers the exposed side. Because the pigmented lesion is much like a collection of small umbrellas covering a collection of cells, the physical makeup of a pigmented lesion is that of a sheet and not a cylindrical target like the vessel of a hair shaft. A sheet of target has a very different and slower TRT than does a cylinder. A cylinder can disperse heat in two of the three possible axes (up/down, left/right, back/forth) but cannot disperse heat longitudinally because the adjacent longitudinal targets contain as much heat.

In a sheet of target, the heat can only be dispersed in the up/down axis because there are similarly heated components both left/right and back and forth. Therefore the thermal relaxation time is double that of a cylinder. The thickness of most pigmented lesions indicates that the TRT should be in the 1-3 millisecond range. However because it is a sheet and not a cylinder the TRT doubles to near 6-10 milliseconds and the ideal pulse time for photo-bleaching falls again to the 3-5 millisecond time window.

How does the practitioner determine which of these 3-5 milliseconds targets will be selected by the device?

The practitioner needs to consider not only the rate of the energy delivery but the fluence delivered in a pulse, the filter used, and the correct number of treatments for the unwanted hair or lesion. The selection of the energy and filter used, as previously described, will focus the intense pulsed light to a specific depth and target allowing the treatment of hair, vessels, or pigmented lesions with deference to, but not isolation of, other targets of color.

CONCLUSION

In the very thin skin structure comprising the epidermis and the dermis there are often unwanted items. The targeting of those items is a function:

- 1) of wavelength to determine depth and nature of the target,
- 2) of power and spot size to generate a specific amount of heat to alter the target and
- 3) the time period in which the energy is delivered.

Most unwanted hair and vascular targets are very similar in size and shape (60-100 micron cylinders). Therefore, they have very similar ideal pulse times.

Pigmented lesions are not as thick as the diameter of the unwanted hair or vessel but they exist in a sheet, which has about twice the TRT resulting in a similar 3-5 millisecond pulse time. It is agreed by practitioners that when there exists a choice of short pulse time (between 3 and 5 milliseconds), it is more preferable to select 5 milliseconds for the sake of safety and reduced discomfort. Longer pulse times (10 milliseconds or beyond) do not have the same ability to match the natural physical responses of these targets and consequently require much more energy, resulting in a greater risk of complications.

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¹ Patrick J. Clark, President of Medical Laser Dynamics, Highland Village, Texas, has been involved with many aspects of clinical laser application. From initial training in 1988 he has worked in areas as diverse as hospital Operating Rooms and Aesthetic Spas. Those tasks have included the building, evaluation, maintenance, safety, education, and administration of both lasers and laser programs across the world. In 1992, Mr. Clark founded the Applied Biophotonics Department at the University of Texas Southwestern Medical Center at Dallas, Texas, USA, which to date has grown to over 160 Class IV light devices. He has 21 published papers and numerous speaking engagements including annual lectures at the US Food and Drug Administration. Mr. Clark's time currently is divided between device development/sales and independent educational and certification programs.

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